

CONSTITUTIVE LAWS FOR SEA ICE DYNAMICS MODELS

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LONG TERM GOALS

The long term goal of my research is to develop sea ice dynamics models that describe behavior on kilometer scales and larger, and to base these models on the smaller scale physical processes known to control leading, rafting, and ridging.

OBJECTIVES

Two objectives were (1) to continue development of the new anisotropic plasticity constitutive law for large scale sea ice behavior, and (2) to analyze data from controlled-load tests conducted during SIMI.

APPROACH

The framework of the new constitutive law was laid out in prior years. It consists of a yield surface, flow rule, elastic closure, and kinematic relationship. The yield surface, which must be described in stress component space (three Cartesian components, not two invariants), is composed of separate surfaces for each lead or ridge system. Ice conditions are described by an oriented thickness distribution. Both of these parts of the constitutive law were presented by *Coon, et al.* [1997a,b], which focuses on describing the physical behavior of ice and relating it to behavior of the anisotropic model. For example, we consider how to satisfy the requirement that a lead may not open when there is a confining stress across it. This requirement leads to restrictions in yield surface shape, and a need to consider a non-normal flow rule.

Pritchard [1997] presented a more formal set of equations, where the ice condition is described by a three-dimensional oriented thickness distribution, rather than a thickness distribution for each lead or ridge system. This formulation allows a more consistent definition of ice strength in different directions.

We are analyzing data from a set of SIMI tests in which ice blocks were towed across the ice sheet. The force balance equation describing this behavior has been derived and solved. Measured force histories are compared with modeled histories.

ACCOMPLISHMENTS

The model formulation is progressing. The anisotropic constitutive law has been outlined. Acceptable yield surfaces and flow rules are now available, as are the elastic closure and kinematic relationship. A three-dimensional thickness distribution describes the oriented ice. We

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must still define ice strength in terms of ice conditions, and test the model in *0d* and *2d* simulations.

Data from the controlled-load tow tests are being used to estimate friction coefficients in the new stick-slip model. A model of the pulling force has been introduced and solved. Results show a definite stick-slip behavior, which is similar to that seen during full-scale ice rafting and ridging events. The stick-slip behavior depends on the elasticity of the surrounding ice sheet. These results, along with the model, are described in a manuscript being prepared for JGR [Pritchard, *et al.*, 1997].

SCIENTIFIC/TECHNICAL RESULTS

The framework of a new anisotropic elastic plastic constitutive law for sea ice has been described and accepted for publication by JGR [Coon, *et al.*, 1997a]. The concept of an oriented thickness distribution has been completed and accepted for publication by JGR [Coon, *et al.*, 1997b]. A more complete mathematical formulation using a general three-dimensional thickness distribution function has been published [Pritchard, 1997].

IMPACT FOR SCIENCE AND SYSTEMS APPLICATIONS

The anisotropic elastic-plastic constitutive law and the oriented ice thickness distribution are new concepts. They allow the ice behavior to be described on scales from as small as a few kilometers up to hundreds of kilometers. For the first time, we can describe the formation and evolution of individual lead and ridge systems, including their orientations.

The anisotropic model will provide a major new capability for the Navy sea ice forecasting needs.

TRANSITIONS

Within the next few years, I expect the new anisotropic plasticity model to be incorporated into the PIPS ice forecasting system, which will provide the Navy with a next-generation model.

RELATED PROJECTS

This work is being conducted in close cooperation with Dr. Max Coon and colleagues at NorthWest Research Associates, Inc. The model development is a collaborative effort. We also conducted the suite of SIMI controlled-load tests together, and are jointly analyzing the results of these tests.

A new task titled *Multiscale Microdynamics of Ice Fields* was subcontracted to Dr. Martin Ostoja-Starzewski. He is reporting on that work separately.

PUBLICATIONS

Pritchard, R. S. (1997) "Ice Conditions in an Anisotropic Sea Ice Dynamics Model," in *Proceedings of the Seventh International Offshore and Polar Engineering Conference*, Int'l. Soc. of Offshore and Polar Engr., Honolulu, HI, May 25-30, pp. 508-513. Also accepted by *J. Soc. Offshore and Polar Engr.*

Coon, M. D., Knoke, G. S., and Echert, D. C., and Pritchard, R. S. (1997a) "The Architecture of a New Sea Ice Mechanics Model," accepted by *J. Geophys. Res.*

Coon, M. D., Knoke, G. S., and Echert, D. C., and Pritchard, R. S. (1997b) "An Oriented Thickness Distribution for Sea Ice," accepted by *J. Geophys. Res.*

Pritchard, R. S., Coon, M. D., Knoke, G. S., and Echert, D. C. (1997) "Sliding Friction of Sea Ice Blocks," to be submitted to *J. Geophys. Res.*